Estuarine Nutrient Enrichment Vital Signs
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Justification of Selection of *Nutrient Enrichment* as Major Issue of Concern in Estuaries:

Approximately one quarter of the NPS land area within the Coastal and Barrier Network is submerged. These estuaries, bays, and lagoons serve as islands of relatively pristine aquatic habitat within the northeastern urban corridor. The North Atlantic coastal parks are dependent on high-quality aquatic resources to sustain the complex estuarine and nearshore ecosystems they represent. Diverse threats to NPS estuaries exist, including natural disturbances (e.g. storms, sea-level rise), direct impacts of human activities (e.g. fishing, boating, dock construction), indirect effects of watershed development, and disasters (*reference Estuaries Habitat Model*). Of these, park managers throughout the network have repeatedly identified threats to coastal water quality as one of their highest priority management issues (see CBN Scoping Workshop Appendix, Documents II and III). Much of the watershed area of NPS coastal ecosystems lies outside protective park boundaries and is subject to intense developmental pressures. Therefore, there is great potential for human disturbances to coastal watersheds to result in increased nutrient loading to park estuaries. Estuaries can generally assimilate some degree of enrichment without major ecological ramifications, but excessive nutrient inputs typically lead to dense blooms of phytoplankton and fast-growing macroalgae, loss of seagrasses, and decreased oxygen availability in sediments and bottom waters. Ultimately, cascading effects include changes in the species composition and abundance of invertebrates, decline in fish and wildlife habitat value, and the collapse of fin- and shellfish stocks. Protecting the ecological integrity of park estuaries depends on implementing a scientifically-based monitoring program that is capable of diagnosing local causes of nutrient enrichment, detecting changes in nutrient loads, and determining if nutrient inputs are near to exceeding thresholds that would result in shifts in ecosystem structure and function.

Prioritization of Vital Signs for Testing

The following monitoring questions guided selection of potential vital signs for estuarine monitoring:

1. Are nutrient loads to park estuaries increasing?
2. Are estuarine resources changing in response to nutrient inputs?
3. What are the sources of nutrient enrichment?

The parameters listed below were considered as potential monitoring variables based on the ability to answer these questions. (Those marked with an asterisk were selected for regional testing – see discussion below).

*SAV distribution
Macroalgal distribution
*Chlorophyll *a* concentration
Total Nitrogen, Phosphorus, and Dissolved Organic Carbon in the water column
Basic Water Quality parameters (dissolved inorganic Nitrogen, dissolved inorganic Phosphorus, *temperature, *salinity, pH)
*Dissolved oxygen
*Depth, spatial extent, and duration of hypoxia
Nutrient loads
Index of biotic integrity (based on fish)
*Turbidity/total suspended solids/*light intensity
Flushing rates
*Land use/land cover in the watershed
*Human population density
*Precipitation quality
*Wastewater discharges, other point-source discharges
Agricultural runoff
*Plant tissue constituents
*Benthic invertebrate species distribution and abundance
Denitrification rates
Fecal indicator bacteria
*SAV population and community characteristics
Indicator species

Individual potential variables were evaluated in terms of established characteristics of effective monitoring variables (see attached Table 1). Some variables were eliminated because they were difficult or costly to measure (e.g. nutrient loading, denitrification rates, agricultural runoff), others because they exhibit high variability (e.g. macroalgal density, dissolved nutrient concentrations), and still others because the predictability of their relationship to nutrient enrichment is still being researched (e.g. index of biotic integrity, indicator species) or is unknown (fecal indicator bacteria). The most effective monitoring programs include variables that span levels of ecological organization (organisms to landscapes), relationships (causes of and responses to stress) and complexity (structure, function, and composition). Consequently, each variable was also evaluated in terms of its relative contribution to a collective suite, with the goal of including representatives of different scales, trophic levels, and relationships to nutrient enrichment. Finally, potential variables were evaluated for consistency with two NPS programs also under development (national water quality monitoring in marine/estuarine waters; water quality inventory protocols for estuarine/marine systems), and with the long-standing Environmental Monitoring and Assessment Program / National Coastal Assessment of the US Environmental Protection Agency. Thus, the final list of candidate indicators for this protocol was influenced by both scientific and practical considerations.

The vital signs that were selected for regional testing are listed below. These variables are currently being tested for logistic and economic feasibility of implementation on a regional scale, and to determine the sampling designs necessary for long-term monitoring.

Agents of Change-

- Land use/land cover
- Nutrient point-source discharge permits
- Atmospheric N deposition
- Housing density
- Permitted water withdrawals for agriculture and domestic consumption
- Fertilizer consumption
- Livestock populations

Ecosystem Responses-

- Dissolved oxygen
- Chlorophyll *a*
- PAR (photosynthetically active radiation) light attenuation
- Turbidity
- Temperature
- Salinity
- SAV distribution
- Within SAV-bed percent cover, shoot density, biomass
- SAV tissue N
- (under consideration also, though may have to undergo further prioritization among Selected Vital Signs – benthic invertebrates, sediment organic carbon)

Links Between Vital Signs and Monitoring

The vital signs selected for regional testing include variables that serve as proxies of nutrient load (Agents of Change variables) and variables that serve as indicators of changing ecological status as a result of nutrient enrichment (Ecosystem Response variables).

Collectively, this suite of variables will provide answers to the original monitoring questions regarding the magnitudes, sources, and effects of nutrient enrichment to park estuaries. Data for Agents of Change variables are already gathered by local, state, and federal agencies. Regional testing involves determining the geographic scope of watershed data relevant for each network park, compiling current and historic (at 10-year intervals back to 1970) data from existing sources, and developing trajectories for each variable over time. This analysis will be used to identify the most useful indicators of nutrient load and to prepare guidance for updating the NPS database from other specific sources.

Methods for monitoring the Ecosystem Response variables are being tested at three parks that represent the range of sizes, estuarine characteristics, complexity, and logistical constraints found throughout the network. A combination of continuous and discrete sampling of chlorophyll *a*, dissolved oxygen concentration, turbidity, attenuation of PAR, temperature, and salinity is being used to encompass the spatial and temporal variability that may be inherent in these variables. Feasibility of monitoring SAV population characteristics and tissue nutrient content as vital signs is being evaluated in contrasting environments at one park (pristine vs highly susceptible to nutrient enrichment). The remaining ecosystem response variables (total organic carbon content of the sediment, benthic faunal species composition, and distribution of SAV) do not require pilot testing before regional implementation, as standard operating procedures and costs for monitoring are well-established within existing programs. Following this feasibility test, the suite of proposed vital signs for monitoring estuarine ecosystem responses to nutrient input will be evaluated and prioritized for cost-effectiveness in the final regional implementation.

Specific Measurable Objectives

For many of the vital signs selected for testing, specific measurable targets do not exist. In some cases, however, the current feasibility test will be useful in identifying thresholds of values that should trigger management concern. In particular, the historical analysis of Agents of Change variables will define the rate of change of these vital signs over the past 30 years. The slopes of these relationships, in comparison with the known status of park ecosystems, may be useful in determining ranges of values that signify major changes in nutrient load. The comparison of SAV tissue nutrient concentrations between a pristine and an impacted site in this feasibility test and in other ongoing research (Neckles, research in progress at Acadia National Park) should also help define thresholds of response for this vital sign. For some variables, measurable targets can be adopted from other programs. Over the past ten years, scientists and managers in the Chesapeake Bay region have summarized an enormous amount of information from inventory, monitoring, and research programs into two technical syntheses of SAV water quality and habitat-based requirements and restoration targets (Batuik et al., 1992, 2000, USEPA Chesapeake Bay Program, Annapolis, MD). Measurable objectives for suspended chlorophyll concentrations (<15 µg/l) and light attenuation (a minimum of 13% to 22% of surface irradiance reaching the canopy, depending on the SAV community type) emerged from these syntheses. These targets are applicable to NPS monitoring of these vital signs as well. Similarly, the US Environmental Protection Agency monitors a suite of estuarine indicators through the Environmental Monitoring and Assessment Program and the National Coastal Assessment, and summarizes these indicators in relationship to specific targets derived from long-term research and monitoring data (National Coastal Condition Report for 2001, USEPA-620/R-01/005). Dissolved oxygen conditions are considered poor when concentrations are less than 2 ppm.

Table 1. Characteristics of effective monitoring variables (after Jackson et al. 2000, NPS 2000, Dale and Beyeler 2001, Kurtz et al. 2001)

Relevant to management concerns and ecological resources
- Address monitoring questions of interest
- Have known linkage to ecological function or critical resource of interest
- Are at appropriate scale to answer specific monitoring questions
- Are integrative in space and time, so that the full suite of variables provides assessment of entire system of interest

Applicable for use in a monitoring program
- Are easy and practical to measure
- Are non-destructive or low impact to measure without disturbing monitoring site
- Are measurable using standard, well-documented methods
- Generate data that are compatible with other systems
- Are cost-effective to measure

Responsive to anthropogenic stresses
- Have known sampling and measurement error
- Have low natural variability
- Have known variability in time and space
- Are sensitive to anthropogenic stresses on the system or resource of interest, while having limited and documented sensitivity to other factors (i.e. to natural variation in ecosystem condition)

Interpretable and useful to environmental decision-making
- Respond to stress in a predictable manner
- Are anticipatory: signal impending change in ecosystem before substantial degradation occurs
- Are linked to management decisions; predict changes that can be averted by management action, or document success of past actions
- Have known or proposed thresholds of response that delineate acceptable from unacceptable ecological condition
- Can be communicated to managers and the public

Dale, V. H. and S. C. Beyeler. 2001. Challenges in the development and use of ecological indicators. Ecological Indicators 1:3-10.

Jackson, L.E., J.C. Kurtz, and W.W. Fisher, eds. 2000. Evaluation Guidelines for Ecological Indicators. EPA/620/R-99/005. U.S. Environmental Protection Agency, Office of Research and Development, Research Triangle Park, NC. 107p.

Kurtz, J. C., L. E. Jackson, and W. S. Fisher. 2001. Strategies for evaluating indicators based on guidelines from the Environmental Protection Agency's Office of Research and Development. Ecological Indicators 1:49-60.

National Park Service (NPS). 2000. A summary of the Coastal and Barrier Network Monitoring Workshop. National Park Service Inventory and Monitoring Program, Coastal and Barrier Network, Report of workshop held April 13th-14th, Gateway National Recreation Area. 21pp + appendices.

ESTUARY HABITAT MODEL

Agents of Change (letters indicate connection to specific Stressors as labeled below)

Natural Disturbance (A, B, C)
- Sea-level rise
- Storms
- Disease
- Shoreline geomorphic processes
- Grazing
- Bioturbation

Land use (A, B, C, D, E)
- Watershed development
- Septic/sewage discharge
- Air pollution
- Coastal construction (dredging, marinas, causeways, docks)
- Shoreline armoring

Resource Consumption (B, C, D)
- Shellfish/finfish harvest
- Aquaculture

Visitor & Recreation Use (B, C, D)
- Boating

Disaster (D)
- Oil spills
- Toxic spills

Stressors

A. Altered Hydrology
- Tidal flow
- Freshwater input
- Waves and currents

B. Altered Landscape
- Fragmentation
- Filling
- Scouring

C. Altered Sediment Processes
- Sedimentation
- Turbidity
- Erosion

D. Altered Chemical Inputs
- Nutrients
- Toxins

E. Altered Atmospheric Inputs
- Nutrients
- Toxins

<u>Ecosystem Responses</u>

Ecosystem Structure Changes
- Species composition and abundance
- Invasive species expansion
- Species declines
- Competitive displacement

Ecosystem Function Changes
- Productivity
- Nutrient cycling
- Energy flow
- Trophic dynamics

Physical Environment Changes
- Water quality
- Sediment chemistry
- Oxygen availability
- Light availability
- Bottom topography